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Quantifying the image quality of the KDC-10 refuelling vision system

TNO Human Factors
Research Institute

Kampweg 5
P.O. Box 23
3769 ZG Soesterberg
The Netherlands

Phone +31 346 35 62 11
Fax +31 346 35 39 77

authors
F.L. Kooi
L. van Breda

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11. AUTHOR(S)

F.L. Kooi and L. van Breda

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TNO Human Factors Research Institute
Kampweg 5
3769 DE SOESTERBERG

13. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Director of Airforce Research and Development
Binckhorstlaan 135
2516 BA DEN HAAG

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De beeldkwaliteit van het bijtank zichtsysteem in de KDC-10 (refuelling vision system, RVS) is bemeten in termen van gezichtsscherpte en contrastgevoeligheid. Voor het meten van de gezichtsscherpte werd de 5 m TNO kaart onder de KDC-10 in het gezichtsveld van de RVS geplaatst. Voor de lastigere zichtcondities waaronder de boomoperator werkt, werd een speciale contrastgevoeligheidstest ontwikkeld. Met deze test is de zichtbaarheid van donkere delen tegen een lichte achtergrond gemeten (representatief voor een "receiving" vliegtuig boven een wit wolkendek). Vergeleken met andere camera systemen scoort de bestaande RVS slecht op de contrast weergave. Een commerciële camera bleek even goed in resolutie en 4 keer beter in contrast weergave. Het blote oog bleek 7 en 20 keer beter in gezichtsscherpte en contrast gevoeligheid. Een recentelijke verbetering in het RVS beeldsysteem laat een gedeeltelijke verbetering zien. In dit rapport wordt de beeldkwaliteit nader geanalyseerd en worden suggesties voor verdere verbetering gegeven. De contrastgevoeligheid kan worden verbeterd door *(i)* het lichtlek van het stereoscopisch scherm te verminderen en *(ii)* de contrastweergave van het camera systeem te verbeteren.

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SUMMARY

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De beeldkwaliteit van het KDC-10 bijtank systeem

F.L. Kooi en L. van Breda

SAMENVATTING

De beeldkwaliteit van het bijtank zichtsysteem in de KDC-10 (refuelling vision system, RVS) is bemeten in termen van gezichtsscherpte en contrastgevoeligheid. Voor het meten van de gezichtsscherpte werd de 5 m TNO kaart onder de KDC-10 in het gezichtsveld van de RVS geplaatst. Voor de lastigere zichtcondities waaronder de boomoperator werkt, werd een speciale contrastgevoeligheidstest ontwikkeld. Met deze test is de zichtbaarheid van donkere delen tegen een lichte achtergrond gemeten (representatief voor een "receiving" vliegtuig boven een wit wolkendek). Vergeleken met andere camera systemen scoort de bestaande RVS slecht op de contrast weergave. Een commerciële camera bleek even goed in resolutie en 4 keer beter in contrast weergave. Het blote oog bleek 7 en 20 keer beter in gezichtsscherpte en contrast gevoeligheid. Een recentelijke verbetering in het RVS beeldsysteem laat een gedeeltelijke verbetering zien. In dit rapport wordt de beeldkwaliteit nader geanalyseerd en worden suggesties voor verdere verbetering gegeven. De contrastgevoeligheid kan worden verbeterd door *(i)* het lichtlek van het stereoscopisch scherm te verminderen en *(ii)* de contrastweergave van het camera systeem te verbeteren.

1 INTRODUCTION

The Royal Netherlands Air Force (RNLAF) presently employs two KDC-10 tanker aircraft for air-to-air refuelling missions. On board of each tanker, a Remotely Aerial Refuelling Operator (RARO) station is installed, enabling the boom operator to remotely control the telescopic boom and to perform the refuelling task. Two joysticks are used to control the boom and visual feedback is provided by the stereoscopic Refuelling Vision System (RVS). The KDC-10 has been operational for about a year. According to the RNLAF, problems arise with the refuelling task. The complaints of the boom operators refer to the quality of the RVS images. There is a strong feeling that the settings for optimal image presentation are inconsistent, and that the quality of the video system is insufficient. During recent refuelling missions, details of the receiving aircraft became nearly invisible in high contrast scenes, so that some of the planned hookups had to be cancelled. It was felt that these defects hamper optimal control, in particular during long periods of operation, and thus decrease the system's safety.

Within this context, the TNO Human Factors Research Institute was asked to evaluate these complaints and advise the RNLAF how to proceed in optimizing the RVS system. Chapter 2 describes the qualitative diagnosis of the defects on the basis of in-flight observations. Chapter 3 discusses a brief experiment in which recent efforts of the RVS manufacturer McDonnell Douglas Aerospace to improve the image were evaluated. Chapter 4 examines (in the laboratory) the unwanted side-effects of the stereoscopic screen. Chapter 5 lists general conclusions and suggestions for RVS improvement.

2 QUALITATIVE DIAGNOSIS

2.1 Method

Observations were made of the refuelling process during a NATO training flight on June 11, 1996, during a rendez-vous with six F-16 fighter aircraft at 30,000 ft altitude above Germany. This was done in good weather daylight conditions, with slight overcast. The images of the RVS system were observed during hookup and refuelling operations. Afterwards, the boom operator was interviewed. There was ample time available to manipulate and try out different camera and monitor settings, and to judge the resulting image quality. Back on the Eindhoven Airport platform, additional observations were made using test patterns placed on the ground behind the stereoscopic cameras.

2.2 Results

1 The system settings appeared to be inconsistent. Repeated system knob setting procedures, performed by the boom operator, did not always affect the image in the same way.
2 The boom operator typically chose the NIGHT camera mode, since details in dark parts of the scene became better visible. In the BRIGHT and NORMAL camera modes, these

parts disappeared into the dark background. For each hookup, the operator carefully selected the best possible iris-setting for the specific visual condition. Under the conditions of the June 11 flight, this setting was always achieved just before complete saturation of the picture.

3 The binocular image exhibited quite a bit of luster. This is the perception of glossiness or sheen, caused by local differences in brightness between the left eye and right eye images (Tyler, 1983). Luster causes eye strain (Kooi, 1993, 1996). To minimize eye strain, the boom operator is tempted to reduce the image contrast by increasing the brightness. Luster in the binocular mode was caused by the following phenomena:
   a an overall brightness difference between the left and right eye image. The difference is most pronounced for high contrast images;
   b crosstalk between the left and right eye image, due to leakage in the binocular mode. The crosstalk is visually most pronounced for high contrast images;
   c binocularly asymmetric horizontal color and brightness gradient across the screen[1];
   d binocularly asymmetric vertical color and brightness gradients across the screen;
   e line raster;
   f the extreme disparity of the boom and background.

4 The quality of the left eye and right eye video images with the view selector in the BINOCULAR mode is inferior to the quality of the left eye and right eye images with the view selector in the MONOCULAR (left and right) mode. Apparently the binocular mode showed less contrast and resolution, probably due to crosstalk.

5 The screen was not free of reflections.

2.3 Potential causes

ad 1 The most favorable video images are obtained near the system limits. In general, knob settings become unreliable under these circumstances and small changes may have large effects.

ad 2 The dynamic (luminance) range of the system is insufficient to represent the most relevant shades of grey. This problem is aggravated by the reduced image contrast due to binocular crosstalk (see factor 3b).

ad 3a Difference in brightness between the left and right images may be caused by difference in gain or shift of the video signals. A standard requirement states that the (local) brightness difference between left and right eye image should not exceed 15% (Beldie & Kost, 1991).

ad 3b Minimal crosstalk requires a fast phosphor and perfect polarization of screen and glasses. In case the phosphor is to blame, a monochrome screen may give better results. The manufacturer of the screen and glasses (Tektronics) should be able to provide detailed specifications.

ad 3c+3d Gradients appear to be caused by stereoscopic scan conversion. In the LEFT or RIGHT camera mode, gradients were less visible.

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[1] The vertical gradient has the shape of a so-called "Cornsweet edge" with a very steep gradient halfway the screen. The horizontal gradient is a gradual slope across the screen.

ad 3e The line raster is either caused by the polarization screen or by the monitor screen. It provides a small amount of stimulus for accommodation which is distracting[2].

ad 3f The extreme disparity of the boom is caused by the large camera separation. If the other causes for luster are eliminated, the extreme boom disparity should not be a problem.

ad 4 The crosstalk mentioned in 3b reduces the contrast in the stereo mode. The video circuitry that creates the binocular image (stereo scan convertor and on-screen graphics) may also degrade the video image.

ad 5 Visual reflections in the screen should be avoided by reducing the light level and glare sources.

2.4 Further steps

In order to quantitatively measure the RVS image quality, TNO proposed to implement a testing and calibration procedure for the RARO RVS. The procedure should be applicable on the platform of any airport. The benefits of a quantitative evaluation are the following:

1 The system can be calibrated according to the specifications. Ideally, these specifications should be provided in detail by McDonnell Douglas Aerospace.
2 Changes in image quality over time can be identified and logged.
3 System improvements can be objectively evaluated.
4 Boom operators will gain added understanding of the RVS and its (many) options and settings.
5 In principle, test charts make it possible to check and optimize RVS settings shortly before take-off.

Test results of such a setup are described in the next Chapter.

2.5 Conclusions

Observations of the KDC-10 refuelling vision system revealed that the image quality of the binocular video system is below par. This is mainly caused by the phenomenon that both left and right eye images have a limited dynamic range and different setpoints (shift). It was advised to request McDonnell Douglas Aerospace to increase the dynamic range and resolution of the vision system, particularly in the BRIGHT and NORMAL camera modes. Furthermore, crosstalk should be reduced. Finally, the settings of the left and right eye video channels must be recalibrated.

3 IMAGE QUALITY MEASUREMENTS

In Chapter 2 it was argued that a procedure is needed to quantitatively describe the image quality of the RVS. From the observations the image contrast and resolution were pinpointed

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[2] A change in accommodation induces a change in vergence which adds to the binocular instability.

as the crucial variables. It was decided to use psychophysical measures to quantify these two parameters. The contrast sensitivity and the visual acuity of the boom operator looking through the RARO viewing system will give a direct measure of the image quality, since the system rather than the observer's eyes is expected to be the limiting factor. The RVS image is compared to that of a commercial camera (Sony, 1990), to the naked eye, and to the RVS image after adjustments had been made by McDonnell Douglas Aerospace ($RVS_{adjusted}$).

3.1 Methods

Ideally the RVS image should be evaluated during flight. For practical reasons it was decided to do the evaluation on the ground, at the Eindhoven Airport tarmac. A standard visual acuity test chart (the TNO 5 m chart), a standard contrast sensitivity chart (the Pelli Robson chart), and a set of newly developed contrast sensitivity charts were placed in front of the cameras at 4.8 m distance. The new charts measure the contrast sensitivity for dark objects, the Pelli-Robson chart for bright objects. The new charts consist of Landolt-C optotypes (10 and 20 cm diameter) varying in the contrast of the letter opening. The step size in contrast is 0.25 logunits, or 1.8 times. This also determines the accuracy of the chart. For more accurate data the measurements will have to be repeated. The letter contrast is defined as the luminance of the gap minus the luminance of the letter divided by the luminance of the background. The TNO acuity chart makes use of the same Landolt optotypes but these vary in size and are fixed in contrast (100%). The accuracy is 0.1 units. For both tests the observer has to indicate the orientation of the gap in the letter C, which can be top, bottom, left, or right. For a more detailed description of the optotype and procedure see ISO (1988). The tests were done during daylight conditions, the luminance of the charts being 2000 cd/m². The subjects read the charts from the boom operator's position. All relevant RVS camera settings were tested: NORMAL-AutoIris, NORMAL-MaxIris, BRIGHT-AutoIris, BRIGHT-MaxIris, NIGHT-AutoIris, and NIGHT-MaxIris. The "Maximum iris" condition simulated the boom-operator strategy to manually turn the iris to the widest possible aperture without washing out the image. At each setting the tests were done in the MONO as well as the STEREO mode. In the stereo mode the observer viewed the screen with one eye through the polarized clip-on glasses[3]. To simulate maximum and minimum crosstalk between the left eye and right eye images, the test charts were surrounded by a white and a black field respectively. The white test charts were just too wide (50 cm) to completely eliminate the crosstalk with the black surround; a 10 cm wide strip of crosstalk remained.

The use of portable test charts allows a direct comparison between the image quality of the four viewing systems. The commercial CCD camera and the naked eye were tested at TNO, using the same charts and the same viewing conditions: 1500 cd/m², 4.8 m effective observation distance, and a field of view equal to that of the RARO RVS. The effect of a stereoscopic screen (NuVision Technologies) on the image quality is discussed in Chapter 4.

[3] Binocular viewing did not make sense because at 4.8 m distance the disparity is too large to fuse the left and right eye images.

In addition, the Sony CCD camera was focused directly on the test charts as well as slightly defocused, as is the case at 4.8 m distance from the RARO RVS.

3.2 Results

The total number of conditions is too large to completely reproduce here. The TNO procedure to measure contrast sensitivity is not suitable for the NIGHT mode because the spatial distortions caused by the astigmatic high pass filtering masks the location of the gap in the Landolt-C optotype. Here we will compare the four systems to each other on the NORMAL setting. The data are presented in Tables I and II. The difference between the monocular and stereo conditions is touched on here and described in more detail in Chapter 4.

Comparison of the RVS systems to the Sony camera and the naked eye

A comparison of the "stereo" and "mono" rows of Tables I and II shows that, with the stereoscopic setting, a lower contrast sensitivity and acuity is reached than with the monocular setting. This effect is further described in Chapter 4. Here it will suffice to say that it points to an image degradation caused by the stereoscopic screen in stereo-mode. The monocular RVS data are therefore most suitable for comparison to the naked eye and the commercial camera.

1 $RVS_{original}$ versus naked eye. The most pronounced result seen in Tables I and II is the far superior visual quality of the natural eye. The natural visual acuity and the natural contrast sensitivity are approximately 7 and 20 (!) times better compared to viewing the RVS image stereoscopically. This enormous difference in visual quality explains the lack in user satisfaction of the KDC-10 boom operators.
2 $RVS_{original}$ versus $RVS_{adjusted}$. In order to improve the image quality, McDonnell Douglas temporarily installed an adjusted RVS system in one of the KDC-10's. A comparison to the original system shows a significant improvement in contrast sensitivity for dark objects (0.28 logunits which is equivalent to 1.9 times) and a slight improvement in resolution (1.2 times). The contrast sensitivity for light objects, measured with the Pelli-Robson chart, shows a slight decline (approx. 0.25 logunits; data not shown). Given that the most crucial task asks for a positioning of two dark objects, i.e. the boom to the receptacle, this shift in contrast resolution is appropriate. The effect on contrast sensitivity for intermediate grey levels has not been examined.
3 $RVS_{adjusted}$ versus Sony. The adjusted RVS display, though improved compared to the original system, is inferior in contrast quality to the Sony CCD camera. The Sony with manual iris setting is 2 times better. It must therefore be possible to further improve the RVS. Focussing the Sony CCD directly at the chart or slightly defocusing it (at infinity) made no difference. It is fair to assume that the same holds for the RVS cameras.

Table I Summary of the **contrast sensitivity** measurements with the TNO contrast optotypes. The camera setting was on "normal". "Surrounding" refers to the luminance of the surrounding which was either black or white. "$RVS_{original}$" is the standard RVS system, "$RVS_{adjusted}$" the newly installed system with adjusted gamma. "Sony" is the commercial CCD camera. "Naked eye" is the measurement with the bare eye. The data are presented in terms of the logarithm of the contrast sensitivity. A "–" means that data were not collected for that particular condition.

		$RVS_{original}$		$RVS_{adjusted}$		Sony		naked eye
	surrounding	Auto-Iris	Max-Iris	Auto-Iris	Max-Iris	Auto-Iris	Max-Iris	
stereo	white	0.76	0.73	1.09	1.05	–	–	–
	black	0.61	1.12	1.12	1.05	–	–	–
mono	–	1.21	1.10	1.52	1.40	1.52	1.78	2.05

Table II Summary of the **resolution** measurements with the TNO visual acuity chart. The data are presented in terms of $arcmin^{-1}$.

		$RVS_{original}$		$RVS_{adjusted}$		Sony		naked eye
	surrounding	Auto-Iris	Max-Iris	Auto-Iris	Max-Iris	Auto-Iris	Max-Iris	
stereo	white	0.225	–	0.375	–	–	–	–
	black	0.275	0.26	0.24	0.25	–	–	–
mono	–	0.375	–	0.5	–	0.4	0.4	2.0

4 THE MONOCULAR AND STEREOSCOPIC SETTINGS

The image quality in the stereo mode is significantly worse than in the monoscopic mode. In order to understand the cause(s) of this difference, laboratory experiments were performed, examining the crosstalk between the left eye and right eye.

4.1 Laboratory measurements of crosstalk

The binocular disparity between the left eye and the right eye images at the 4.8 m test distance is too large to fuse the left and right images. It therefore only makes sense to view the stereoscopic test image with one eye at a time. Pictures of a left eye and the corresponding right eye image are presented in Fig. 1.

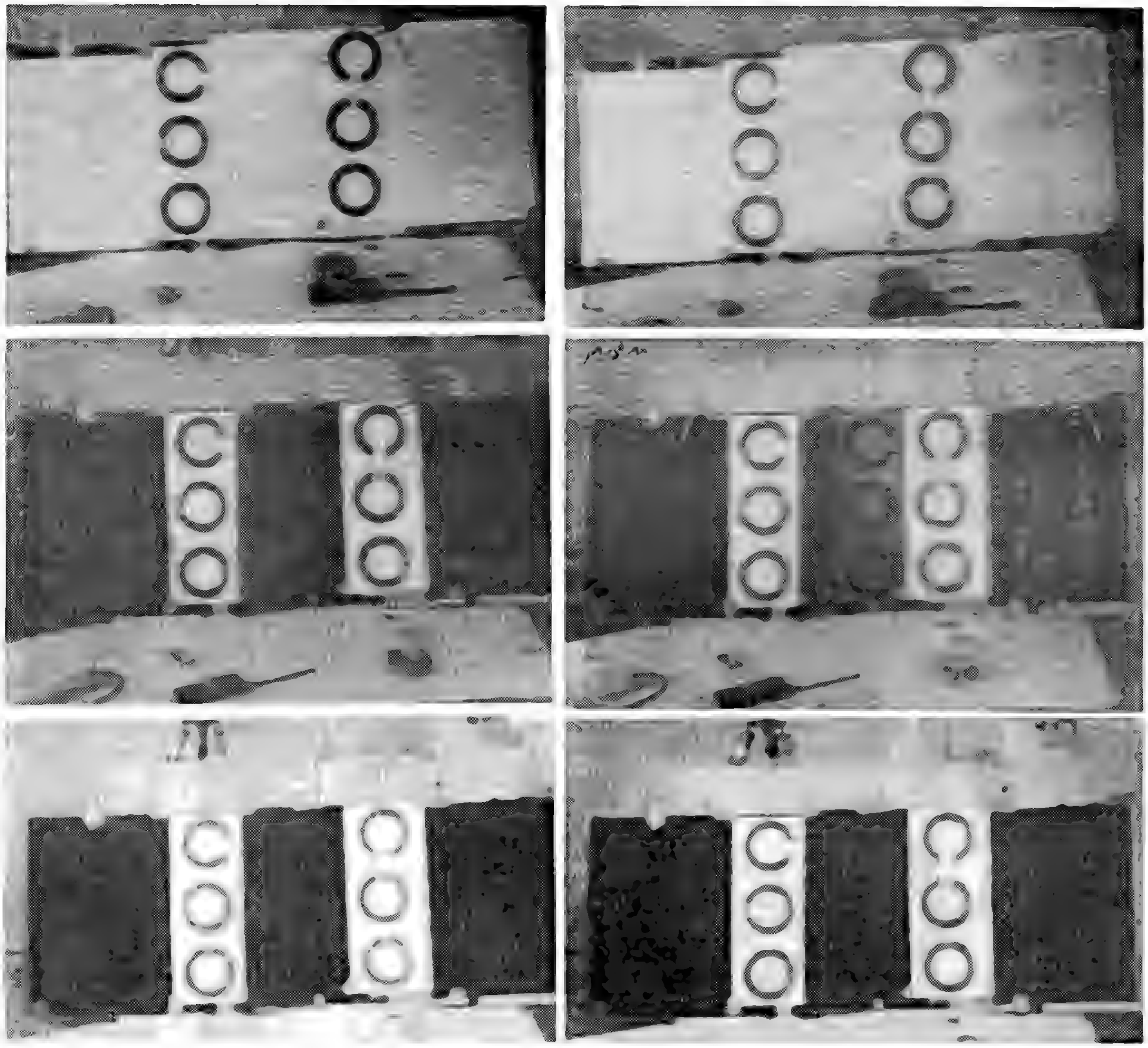

Fig. 1 Pictures taken of the RVS image from the position of the boom operator. Shown are two 20 cm TNO contrast charts. *Left:* the left camera view. *Right:* the right camera view. *Top:* the stereoscopic mode with white surrounding the test charts. *Middle:* the stereoscopic mode with black surrounding the test charts. *Bottom:* the monocular mode. The system setting for each is NORMAL with auto-iris. The stereoscopic crosstalk is visible as a ghost-image of the test charts.

The aforementioned crosstalk is clearly visible as a ghost image. Crosstalk is defined as the luminance 'leakage' of the right channel image into the left channel, and vice versa. In order to quantify the level of crosstalk, a stereoscopic test battery was set up in the laboratory. A Silicon Graphics Onyx generated test patterns, presented on a 19" Tectronix monitor with a NuVision 3 segment stereo-shutter. This shutter is not exactly the same as the one used in the RARO RVS (2 segment screen?). According to Bos (1993) a 3 segment shutter is slightly better than a 2 segment shutter. The test pattern consisted of a large black field in one image and red, green, blue, and white strips in the other. If the shutter worked perfectly, one eye should see nothing (black) and the other the colored pattern. The amount of light shining through in the "black" image therefore defines the level of crosstalk. The luminances were measured with a LMT photometer at the vertical middle of the screen. The results with the black image in the left and right channel are shown in Table III. The crosstalk is significant and asymmetric between the two channels: 9.3% and 19.6% for white. The right eye channel is more degraded. Of the three colors red is relatively little affected by crosstalk (5.4% and 16.8%) and blue the most (14.2% and 22.7%). The effect of the crosstalk on the contrast in an actual image can then be calculated according to the formula

$$\text{contrast reduction} = \frac{(L_t + pL_s)}{L_t}$$

where
contrast reduction = the loss in contrast due to the crosstalk
L_t = the target luminance
L_s = the surround luminance, at the location 50 cm next to the target[4]
p = the proportion of light that is leaked through by the stereo-shutter.

Table III Crosstalk measured with a 3 segment stereoscopic shutter system in the laboratory. The percentage of light that is leaked to the left and the right eyes is given for each of the phosphors.

phosphor(s)	crosstalk (%) seen by	
	left eye	right eye
red	5.4	16.8
green	9.9	17.3
blue	14.2	22.7
white (R+G+B)	9.3	19.6

[4] This distance is dictated by the separation between the two cameras. It is the distance between the targets in the stereo-pair.

Sample calculations are shown in Table IV. The Table can be read as follows. Suppose that the boom has a luminance of 20 cd/m² and is seen against a background of 100 cd/m². (It must be kept in mind that the light levels in Table IV do not refer to the outside environment but to the light levels of the *monitor*.) The contrast of the boom is then reduced by a factor 1.25 and 1.5, for 10% and 20% crosstalk respectively. The darker the target object and the brighter the surround luminance, the larger the reduction in contrast. It is clear that a worst case scenario would be a shaded receiving aircraft above an illuminated cloud cover.

Table IV Calculated reduction in contrast due to crosstalk with the stereoscopic shutter system in the laboratory. The reduction in contrast of a target object of a certain luminance on a surround field with the specified luminance is shown. The first number is the reduction for 10% crosstalk, the second number for 20% reduction. See the text for an explanation.

		surround luminance											
		100		50		20		10		5		0	
crosstalk		10%	20%	10%	20%	10%	20%	10%	20%	10%	20%	10%	20%
target luminance	1	11	21	6	11	3	5	2	3	1.5	2	1	1
	2	6	11	3.5	6	2	3	1.5	2	1.25	1.5	1	1
	5	3	5	2	3	1.4	1.8	1.2	1.4	1.1	1.2	1	1
	10	2	3	1.5	2	1.2	1.4	1.1	1.2	1.05	1.1	1	1
	20	1.5	2	1.25	1.5	1.1	1.2	1.05	1.1	1.03	1.05	1	1
	50	1.2	1.4	1.1	1.2	1.04	1.08	1.02	1.04	1.01	1.02	1	1

Reduction in light level by the stereoscopic screen

The stereoscopic screen also acts as filter and reduces the amount of light coming from the monitor. The reduction in the monoscopic mode is less than the reduction in the stereoscopic mode since the polarized glasses do not need to be worn. The screen by itself reduces the light level to 38%. In combination with the polarized glasses the light coming from the monitor in 120 Hz mode is reduced to 12.8%. The reductions are the same for the three phosphors. In a control experiment it was verified that the stereoscopic screen, with or without the polarized glasses, does not degrade the image quality of a non-stereoscopic image; it only reduces the light level.

4.2 Comparison of the laboratory measurements to the contrast sensitivities

The test charts used in the RVS experiment at Eindhoven Airport (Fig. 1) consisted of a dark letter with either a white or a black surround. At a typical contrast threshold (say 0.6), the gap luminance was 550 cd/m² on the 2000 cd/m² background. According to the above

formula, the reduction in contrast due to the crosstalk, with a *white* surround, should have been

$$\frac{(L_t+pL_s)}{L_t} = \frac{\{550+0.1*2000\}}{550} = 1.36 \quad (10\%\ \text{crosstalk})$$

$$\frac{(L_t+pL_s)}{L_t} = \frac{\{550+0.2*2000\}}{550} = 1.7 \quad (20\%\ \text{crosstalk})$$

which is equal to 0.14 and 0.24 logunits respectively. With a *black* surround no reduction in contrast sensitivity is expected. In Table V the calculations are compared to the data. The measured difference in contrast sensitivity between the monocular and stereoscopic conditions is larger than that based on the calculations: on average 0.3 and 0.2 logunits for the black and white surround respectively. The lower than expected sensitivity with the black surround is partially caused by the remaining crosstalk (§ 3.1). Still we did not expect the large loss of sensitivity in the stereo mode and it may point to an additional source of contrast loss.

Table V The difference between the monocular and stereoscopic contrast sensitivity scores. The theoretical values are calculated according to equation 1. The data are derived from Table I.

		theory	$RVS_{original}$		$RVS_{adjusted}$	
difference in mono−stereo contrast sensitivity scores	surrounding		Auto-Iris	Max-Iris	Auto-Iris	Max-Iris
	white	0.14−0.24	0.45	0.37	0.43	0.35
	black	0	0.6	0	0.4	0.35

Left eye and right eye asymmetry

Table III shows that the crosstalk of a stereoscopic screen can be very asymmetric. The 3 segment system in use at TNO presents a better left eye image. The same trend is present in the measurements collected on the RVS. In the stereoscopic mode the left eye scores slightly better than the right eye. The difference is too small to be very reliable, however (on average 0.01 ± 0.12 for one subject and .05 ± 0.15 for the other). In the monocular mode no difference was found.[5]

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[5] A curious thing is that Bos (1993) writes that the left eye should receive a *worse* image than the right eye. The reason for this discrepancy is at present unclear.

4.3 Conclusions

The leakage of the stereoscopic screen causes significant reduction in image contrast, in particular for dark objects on a white surround. The relevant location of the "surround" is 50 cm to the left and right of the object for the right and left eye views. A receptacle placed more than 50 cm from the edge of the receiving aircraft will suffer less from the crosstalk than a receptacle placed at the side of the aircraft. Due to the asymmetric nature of the crosstalk, a receptacle on the one side should be more visible than on the other side. Crosstalk may be minimized with a better screen and faster, so-called "rare earth", phosphors. The calculations in Table IV and the results in Table V by how much the image contrast can in principle be improved in the "STEREO" mode.

5 GENERAL CONCLUSIONS AND SUGGESTIONS

1 The main problem encountered in the RVS image is the lack of adequate contrast sensitivity for dark structures.
2 There is a considerable loss of contrast due to the stereo screen. On theoretical grounds the loss is expected to be largest for a dark object on a light background. This loss is at least in part due to the leakage of the LCD shutter screen and is asymmetric between the two eyes. This means that a receptacle mounted on one side of the receiving aircraft will be less visible than a receptacle mounted on the other side.
3 A set of test charts has been developed to quantify the contrast sensitivity for dark objects of various sizes.
4 The temporary modification by McDonnell Douglas Aerospace ($RVS_{adjusted}$) improved the contrast sensitivity for dark objects with, on average, 0.28 logunits (a factor of 1.9), compared to the $RVS_{original}$. The sensitivity for medium grey and light objects may have suffered.
5 Comparison with a commercial, off-the-shelf, Sony CCD camera shows that it must be possible to improve the RARO RVS image quality even further.
6 The filtering of the NIGHT setting causes spatial distortion of contrast edges and appears to be more useful in the wrong section of the light domain (for light objects rather than for the more relevant dark objects).

The following suggestions are made:
1 The RVS image quality must be further improved. Resolution and level of contrast sensitivity of the RVS were low compared to that of the commercial camera. Changes in the gamma of the look-up table, as was implemented by McDonnell Douglas Aerospace in October 1996, did improve the image quality. However, in our view, not sufficiently. The changes made by McDonnell Douglas Aerospace ($RVS_{adjusted}$) resulted in a 1.9 times improvement in contrast detection, and possibly a small improvement in resolution. The contrast sensitivity of the natural eye still exceeds the $RVS_{adjusted}$ by 9 times. Matching the quality to the commercial Sony CCD camera will require a further improvement of 2 times.

2 It is questionable if the changes in camera gamma will sufficiently improve boom control. The contrast between the image of the boom and the receiving aircraft (grey on grey) with the $RVS_{adjusted}$ is still too limited. The contrast may be improved by painting parts of the boom dark. A limited experiment could confirm this.

3 Stereoscopic crosstalk may be reduced considerably by replacing the RVS monitors with fast-decay phosphor screens and by updating the stereoscopic screen. We advice to first quantitative confirm the improvement before implementing such a change.

4 Automatic brightness control is more useful if it is triggered by the luminance level of the receiving aircraft rather than the luminance level of the overall picture, which includes the background.

5 Calibration procedures need to be developed to safeguard the quality of the displayed image. It is essential, that these procedures are simple and feasible on the platform, with the RVS camera system still mounted on the KDC-10. Results should be reported to the RNLAF on a regular basis. The RNLAF should keep a log-book of all results, complaints and defects, including continuing problems. This will help to more objectively judge the RVS image quality in the future. TNO could assist in developing these procedures by providing objective assessment of image quality improvements.

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Sony Corporation (1990). 3CCD color video camera DXC-327PK. The spatial resolution is 752×582 (h/v). Signal to noise ratio is 58 dB at 2000 Lux, F5.6 and 3200 K. At 16 lux the sensitivity is only 16 dB.

Soesterberg, 4 December 1996

Dr. F.L. Kooi
(1st author)

Ing. L. van Breda
(project manager)

LIST OF ABBREVIATIONS

RVS	Refuelling Vision System
$RVS_{original}$	The present system
$RVS_{adjusted}$	The system which was tested for two weeks in october 1996
RNLAF	Royal Netherlands Air Force
RARO	Remotely Aerial Refuelling Operator
KDC-10	The DC-10 fitted with the RARO system
Auto-Iris	The iris control of the RVS on automiatic
Max-Iris	The iris control set at the largest aperture before wash-out
3CCD camera	A "Charge Coupled Device" camera with three detector chips

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11. AUTHOR(S)

F.L. Kooi and L. van Breda

12. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

TNO Human Factors Research Institute
Kampweg 5
3769 DE SOESTERBERG

13. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Director of Airforce Research and Development
Binckhorstlaan 135
2516 BA DEN HAAG

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15. ABSTRACT (MAXIMUM 200 WORDS, 1044 BYTE)

The image quality of the KDC-10 refuelling vision system has been evaluated in terms of resolution and contrast sensitivity. To this aim a new contrast test was developed. A comparison to other systems shows that the KDC-10 refuelling vision system is particularly lacking in its contrast representation. A recent adjustment to the system partially improved its characteristics. Part of the poor contrast representation is due to the incomplete image separation of the stereoscopic screen. On the basis of a quantitative analysis of the image quality recommendations for further improvement are given.

16. DESCRIPTORS	IDENTIFIERS
Contrast Sensitivity Image Quality Resolution Stereoscopic Crosstalk Stereoscopic Screen	

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